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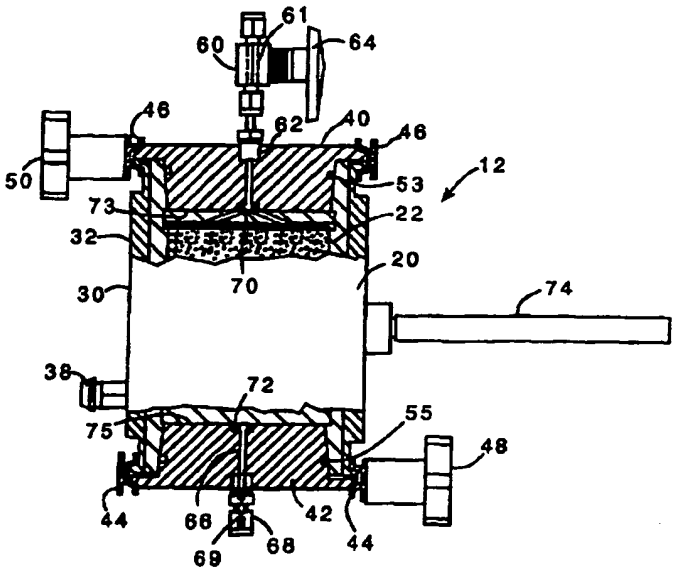
(54) Title: LIQUID CHROMATOGRAPHY COLUMN



(57) Abstract

A chromatography cartridge assembly (12) includes a cartridge (22) with flexible wall defining a chamber, and porous, polymeric, hydrophilic, chromatography media contained within the chamber. The chromatography media have an operating pressure greater than 3 bars. The flexible wall has a moving diaphragm for compressing the chromatography media. The chromatography cartridge assembly (12) includes a flow distributor, flow collector, and sieves formed from a hydrophilic material. A compression module (20) defines a pressure chamber for containing a pressurized fluid. The pressurized fluid acts to move the flexible wall of the cartridge assembly (12). The compression module (20) has a pressure rating greater than 3 bars.

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LIQUID CHROMATOGRAPHY COLUMN

Background of the Invention

This invention relates to liquid chromatography columns useful in biomolecule separations.

Matrix materials used in liquid chromatography for separations of biomolecules must be hydrophilic to prevent denaturation of the biomolecule leading to precipitation and non-specific adsorption on the matrix material. Standard matrix materials used for bioseparations have been soft gels such as sepharose® with pressure ratings up to 3 bars. This limits the pressure that can be applied to the process fluid, thus limiting the speed of separation. Matrix materials have conventionally been packed in glass or stainless steel housings.

Advances in materials technology have led to the development of a new class of polymeric, hydrophilic and rigid support matrices that have much higher pressure ratings and can achieve better resolution. These materials include Emphaze™, POROS®, HyperD™, Fractogel®, and Source™.

Summary of the Invention

The invention features, in general, a chromatography cartridge assembly including a cartridge with a flexible wall defining a chamber, and a polymeric, hydrophilic, chromatography media contained within the chamber. The chromatography media has an operating pressure rating greater than 3 bars. The flexible wall forms a movable diaphragm for compressing the chromatography media.

In preferred embodiments, the media has a particle size in the range of about 15-200 microns. The chromatography media is selected from the group consisting of Emphaze™, POROS®, HyperD™, Source™, Toyopearl®, and Fractogel® media. The chromatography

cartridge assembly includes a flow distributor, flow collector, and sieves formed from a hydrophilic material. There are seals located between the flow distributor and an inner surface of the flexible wall and between the flow collector and an inner surface of the flexible wall. The seal is an o-ring or is formed by welding the flow distributor and flow collector to the inner surface. The movable diaphragm radially compresses the chromatography media. The cartridge has a diameter of at least about 3 inches.

According to another aspect of the invention, a chromatography apparatus includes a compression module surrounding the cartridge assembly. The compression module defines a pressure chamber for containing a pressurized fluid. The pressurized fluid acts to move the flexible wall of the cartridge assembly.

In preferred embodiments, the chromatography apparatus includes first and second end caps for securing the chromatography cartridge assembly within the compression module. The end caps define passages for flow of process fluid. A flow distributor includes an inlet aligned with the passage of the first end cap. The flow distributor inlet and the passage of the first end cap define a process fluid inlet channel. The first end cap has a seal located between the first end cap and the flow distributor for preventing leakage of process fluid from the inlet channel. A flow collector includes an outlet aligned with the passage of the second end cap. The flow collector outlet and the passage of the second end cap define a process fluid outlet channel. The second end cap has a seal located between the second end cap and the flow collector for preventing leakage of process fluid from the outlet channel. The seals keep the compression module free of process fluid contamination during use. A pressure source is connected

to the compression module. The compression module has a pressure rating greater than 3 bars, and preferably greater than 10 to 15 bars.

According to another aspect of the invention, a chromatography cartridge assembly includes a flexible walled cartridge defining a chamber for containing chromatography media; a flow distributor for distributing process fluid across a cross-sectional area of the chamber; a flow collector for collecting process fluid from across a cross-sectional area of the chamber; and two sieves, one on either end of the chamber, for retaining the chromatography media in the chamber. The sieves prevent passage of the media while permitting passage of the process fluid. The flow distributor, flow collector, and sieves are formed of hydrophilic material.

In preferred embodiments, the hydrophilic materials have a surface energy greater than about 36 dyn/cm.

According to another aspect of the invention, a chromatography method includes providing a chromatography cartridge assembly, applying compression to the chromatography media, and supplying a pressurized biomolecule sample in an aqueous based solvent.

In preferred embodiments, the sample is supplied at a pressure greater than 3 bars. The compression is applied to the chromatography media in a radial direction and is greater than or equal to the pressure of the sample.

According to another aspect of the invention, a method of revitalizing a packed column having trapped air includes applying compression, e.g., in a radial direction, to chromatography media to minimize the volume of trapped air.

Advantages include liquid chromatography of biomolecule process fluids under pressures above 3 bars.

The materials used in the chromatography apparatus prevent biomolecule precipitation and non-specific adsorption. The cartridge within a module system permits changeout of wetted components and reuse of the module for different biomolecules without cross-contamination.

Other advantages and features of the invention will ba apparent from the following description of a preferred embodiment thereof and from the claims.

Brief Description of the Drawings

The drawings will be described first.

Drawings

Fig. 1 is a schematic of a chromatography apparatus according to the invention;

Fig. 2 is a partially cut-away, cross-sectional side view of the pressure module of the invention;

Fig. 2A is a top view of the pressure module of Fig. 2;

Fig. 2B is an enlarged view of the clamping region of the pressure module of Fig. 2;

Fig. 3 is a partially cut-away, cross-sectional side view of a cartridge assembly of the invention;

Fig. 4 is a cross-sectional side view of a distributor and mesh of the invention;

Fig. 4A is a sectional view of the distributor of Fig. 4, taken along lines 4A-4A;

Fig. 5 is an enlarged schematic view of a sealing scheme of the invention; and

Fig. 6 is an enlarged schematic view of an additional sealing scheme of the invention.

Description of the Preferred Embodiment

Referring to Fig. 1, an apparatus 10 is shown for performing chromatography separation of biomolecules, e.g., proteins, oligosaccharides, large DNA molecules, and viral particles, in an aqueous based solvent. The

term biomolecules is not meant to include synthetic organic chemicals, small linear peptides, or chiral compounds. Apparatus 10 includes a chromatography assembly 12 and inlet solution tank 2, load tank 3, and system pump 4 for delivering process fluid under pressure along a process inlet path 14 to chromatography assembly 12. An outlet line 5 leads from chromatography assembly 12 to a product collection vessel 6 and a waste receptacle 7. A water filter, bubble trap and monitor 8 (monitoring, e.g., pressure, conductivity, and pH) are located along the process fluid inlet path 14. A monitor 9 monitoring, e.g., pressure, conductivity, pH, and UV absorbance, is located along outlet line 5. A column bypass 16 permits the system to be cleaned while bypassing the chromatography assembly. Valves 15 control the flow of the process fluid.

Referring to Figs. 2-2B, chromatography assembly 12 includes a compression module 20 and a cartridge assembly 22. Compression module 20 includes a housing 30, formed from, e.g., stainless steel or aluminum, defining a cylindrical region 32 for containing fluid for applying radial compression to cartridge assembly 22. A compressible or incompressible fluid can be used to apply radial compression pressure to cartridge assembly 22.

The application of radial compression to a chromatography cartridge is described in U.S. Patent No. 4,250,035 to McDonald, hereby incorporated by reference. Briefly, in a liquid chromatography column, a stationary phase such as silica is packed in a cartridge having a flexible wall. By exerting radial pressure on the cartridge, packing bed voids are avoided and wall channeling effects are overcome. The packing efficiency of the column is increased and is more reproducible, and greater uniformity can be achieved in column performance

both among packed columns of the same kind and during the useful life of a given packed column.

Referring to Figs. 1 and 2A, housing 30 includes a fluid inlet 34, a relief valve 36 for purging pressure within cylindrical region 32, and a pressure indicator 38. Radial compression pressure applied to cartridge assembly 22 is controlled by a pressure regulator or a pump (not shown) which delivers fluid to fluid inlet 34; solvent flow rate through the cartridge assembly is controlled by pump 4. A mounting arm 74 connected to housing 30 can be used to mount chromatography assembly 12 to a laboratory stand.

Removable end caps 40, 42 retain cartridge assembly 22 in place within compression module 20. Referring particularly to Fig. 2B, end cap 42 is mounted to housing 30 with a band clamp 44 (end cap 40 is similarly mounted to housing 30 with a band clamp 46). Clamp tightening knobs 48, 50 are used to tighten band clamps 44, 46 respectively. At higher pressures, the knobs can be replaced with bolts to meet code requirements. As shown in Fig. 2B, each end cap 40, 42 is sealed against housing 30 with an o-ring 52 to prevent leakage of compression fluid from region 32. As shown in Fig. 2, end caps 40, 42 are sealed against cartridge assembly 22 by o-rings 53, 55, respectively, which separate compression fluid from process fluid.

An inlet connector 60 defines a channel 61 leading to an inlet passage 62 defined by end cap 40 for flow of process fluid into cartridge assembly 22. Control knob 64 is used to open and close channel 61. An outlet passage 66 defined by end cap 42 leads to an outlet connector 68 defining a channel 69 for flow of process fluid out of cartridge assembly 22. Inlet and outlet passages 62 and 66 include o-ring seals 70, 72, respectively, for sealing the passages against cartridge

assembly 22. End caps 40, 42 are preferably made from a hydrophilic material, e.g., stainless steel, to prevent precipitation of biomolecules on the surfaces of passages 62, 66. Seals 70 and 72 prevent flow of process fluid along the interface 73 between end cap 40 and cartridge 22 and the interface 75 between end cap 42 and cartridge 22 thus minimizing the exposure of the process fluid to dead spaces and crevices in which microbial growth and attachment could occur.

Referring to Fig. 3, cartridge assembly 22 has a flexible wall 80 partially defining a media chamber 82. Flexible wall 80 further defines end cap receiving openings 84, 86. The upper and lower ends 88, 90 of media chamber 82 are defined by flow assemblies 92, 94 respectively. Upper flow assembly 92 includes a flow distributor 100 and a sieve 102, e.g., a mesh or frit. A mesh is preferred over a frit due to its smaller surface area which limits biomolecule adhesion. Lower flow assembly 94 includes a flow collector 104 and a sieve 106. The flow distributor 100, flow collector 104, and sieves 102, 106 are preferably made from hydrophilic materials having surface energies greater than about 36 dyn/cm, e.g., polyamide, polyethyleneterephthalate, polyvinylidene chloride, polymethylmethacrylate, and polystyrene, to limit biomolecule binding to the surfaces and clogging of the sieves.

Referring to Figs. 4 and 4a, sieve 102 is welded to flow distributor 100 along outer periphery 103 of flow distributor 100. Welding along periphery 103 permits process fluid to flow through sieve 102 but not around it, and prevents media particles from leaking around sieve 102 into flow distributor 100. Sieve 106 is similarly welded to flow collector 104.

The process fluid path is from inlet passage 62 to an inlet 110 of flow distributor 100. Multiple flow

channels 112, 8 channels being shown in the illustrated embodiment, run from inlet 110 to outlets 114. Outlets 114 connect flow channels 112 to a network of channels 116 which distribute the process fluid. Sieve 102 preferably has a pore size of about 10-20 micron to allow passage of process fluid while preventing passage of chromatography media. Flow collector 104 and sieve 106 are identical to flow distributor 100 and sieve 102. Flow collector 104 and sieve 106 are mounted such that process fluid first passes through sieve 106 and then through the network of channels 116 to finally be collected at inlet 110.

An alternative or additional sealing scheme which further limits voids and dead spaces in which process fluid can be trapped is shown in Fig. 5. Here, an o-ring 121 positioned between flow distributor 100 and cartridge wall 80 prevents flow of process fluid around edge 123 of the flow distributor and into crevices where the process fluid can be trapped. Similarly, an o-ring can be positioned between flow collector 104 and cartridge wall 80. Additionally, referring to Fig. 6, the flow distributor and/or flow collector can be welded at 130 along edge 123 and side portions 132, 134 to the cartridge wall, thereby creating a low dead volume seal.

Example operating pressure (process fluid flow pressure) ratings achievable with chromatography assembly 12 employing an aluminum compression module 20 are listed below. For an incompressible compression fluid, the operating pressure can be equal to the pressure rating of the pressure module. For a compressible compression fluid, the operating pressure is about 1 to 6 bars less than the pressure rating of the pressure module because the compression pressure applied to the cartridge is greater than the process fluid pressure to maintain the integrity of the cartridge. Higher pressure ratings are

achievable depending upon tube thickness and by substituting stainless steel for aluminum.

inner diameter of compression module 20 (mm)	pressure (bar)
75	20-35
100	14-23
150	10-17
300	6-14
400	4-10

Referring again to Fig. 3, chromatography media 120 is contained within media chamber 82 by upper and lower sieves 102, 106. Due to recent advances in materials technology leading to the development of the new hydrophilic and rigid support matrices having high pressure ratings, the high pressure ratings achievable with chromatography assembly 12 and the hydrophilic materials used in the critical components of cartridge assembly 22 enable fast, high resolution biomolecule separation. Suitable matrices for chromatography media 120 include Emphaze™, available from Pierce; POROS®, available from PerSeptive Biosystems; HyperD™, available from BioSepra; Source™, available from Pharmacia Biotech, Sweden; Toyopearl® available from TosoHaas, and Fractogel®, available from E.Merck, Germany. The media listed above have particle sizes in the range of 15-100 microns, though media can be used having larger particle sizes, up to at least about 200 microns. The pressure ratings and available functionalities of each material are listed below.

Matrix	Pressure Rating (bar)	Available Functionalities
POROS®	100	ion exchange hydrophobic interaction affinity
HyperD™	200	ion exchange affinity
Emphaze™	7	affinity
Fractogel®	10	ion exchange hydrophobic interaction affinity
Toyopearl®	at least 7	ion exchange hydrophobic interaction affinity
Source™	50	ion exchange hydrophobic interaction

All media have pressure ratings above 3 bars, above 5 bars, and some have pressure ratings about 50 bars, with one having a rating greater than 150 bars.

The radial pressure applied to the chromatography media should be at least equal to the flow pressure of the process fluid to maintain the integrity of the column. When using a compressible compression fluid, the radial pressure applied is in the range of about 1 to 6 bars over the operating pressure.

The surfaces of chromatography assembly 12 exposed to process fluid include cartridge 22, flow distributor 100, flow collector 104, sieves 102, 106, and end caps 40, 42. As discussed previously, the flow distributor, flow collector and sieves are formed from hydrophilic materials to prevent biomolecule precipitation and non-specific adsorption. The sieves are preferably polymeric as opposed to stainless steel due to the stainless steel's poorer chemical resistance and susceptibility to chloride attack. Because the surface area of cartridge 22 exposed to the process fluid is much less than that of

the flow distributor, flow collector, and sieves, cartridge 22 can be formed from a less hydrophilic material, e.g., polyethylene having a surface energy of 35.7 dyn/cm (linear PE) and 35.3 dyn/cm (branched PE). Though to minimize biomolecule precipitation and non-specific adsorption on the cartridge, preferably a more hydrophilic material is also used for cartridge 22. End caps 40, 42 are preferably stainless steel.

Seals 53, 55, 70, 72 insure that compression module 20 remains free of contamination from process fluid during use. The components of cartridge assembly 12 with wetted surfaces can be changed while the same compression module 20 can be used with a new sample without cross-contamination.

It is understood that separate inserts can be employed to define passages 62, 66 such that end caps 40, 42 are not exposed to process fluid and only the inserts need be removed and exchanged or cleaned between sample runs.

It has been found that radial compression can revitalize a packed column. Trapped air in the media causes bed cracking and loss of chromatographic efficiency. By subjecting the column to radial compression, the volume of air is minimized thus minimizing the effects of air entrapment such that there is little or no decrease in performance of the column.

Other embodiments of the invention are within the scope of the following claims.

What is claimed is:

1. A chromatography cartridge assembly comprising

a cartridge including a flexible wall defining a chamber, and

a polymeric, hydrophilic, chromatography media contained within said chamber, said chromatography media having an operating pressure rating greater than 3 bars, said flexible wall forming a movable diaphragm for compressing said chromatography media.

2. The chromatography cartridge assembly of claim 1 wherein said media has an operating pressure rating greater than about 5 bars.

3. The chromatography cartridge assembly of claim 1 wherein said media has an operating pressure rating greater than about 50 bars.

4. The chromatography cartridge assembly of claim 1 wherein said media has an operating pressure rating greater than about 150 bars.

5. The chromatography cartridge assembly of claim 1 wherein said chromatography media has a particle size in the range of about 15-200 microns.

6. The chromatography cartridge assembly of claim 1 wherein said chromatography media is selected from the group consisting of Emphaze™, POROS®, HyperD™, Source™, Toyopearl®, and Fractogel® media.

7. The chromatography cartridge assembly of claim 1 further including a flow distributor formed from a hydrophilic material.

8. The chromatography cartridge assembly of claim 7 further including a seal between said flow distributor and an inner surface of said flexible wall.

9. The chromatography cartridge assembly of claim 8 wherein said seal comprises an o-ring.

10. The chromatography cartridge assembly of claim 8 wherein said seal comprises a weld.

11. The chromatography cartridge assembly of claim 1 further including a flow collector formed from a hydrophilic material.

12. The chromatography cartridge assembly of claim 11 further including a seal between said flow collector and an inner surface of said flexible wall.

13. The chromatography cartridge assembly of claim 12 wherein said seal comprises an o-ring.

14. The chromatography cartridge assembly of claim 12 wherein said seal comprises a weld.

15. The chromatography cartridge assembly of claim 1 further including a sieve formed from a hydrophilic material.

16. The chromatography cartridge assembly of claim 1 wherein said movable diaphragm radial compresses said chromatography media.

17. The chromatography cartridge assembly of claim 1 wherein said cartridge has a diameter of at least about 3 inches.

18. A chromatography apparatus comprising a cartridge assembly comprising a flexible wall defining a media chamber, and a porous, polymeric, hydrophilic, chromatography media contained within said media chamber, said chromatography media having an operating pressure rating greater than 3 bars, said flexible wall forming a movable diaphragm for radially compressing said chromatography media, and a compression module surrounding said cartridge assembly, said compression module defining a pressure chamber for containing a pressurized fluid, said pressurized fluid acting to move said flexible wall.

19. The chromatography apparatus of claim 18 further including first and second end caps for securing said chromatography cartridge assembly within said compression module.

20. The chromatography apparatus of claim 19 wherein said first and second end caps define passages for flow of process fluid.

21. The chromatography apparatus of claim 20 wherein said cartridge assembly includes a flow distributor, said flow distributor including an inlet aligned with said passage of said first end cap, said flow distributor inlet and said passage of said first end cap defining a process fluid inlet channel, said first end cap further including a seal located between said first end cap and said flow distributor for preventing leakage of process fluid from said inlet channel.

22. The chromatography apparatus of claim 20 wherein said cartridge assembly includes a flow

collector, said flow collector including an outlet aligned with said passage of said second end cap, said flow collector outlet and said passage of said second end cap defining a process fluid outlet channel, said second end cap further including a seal located between said second end cap and said flow collector for preventing leakage of process fluid from said outlet channel.

23. The chromatography apparatus of claim 20 wherein said cartridge assembly further comprises a flow distributor and a flow collector,

said flow distributor including an inlet aligned with said passage of said first end cap, said flow distributor inlet and said passage of said first end cap defining a process fluid inlet channel, said first end cap further including a seal located between said first end cap and said flow distributor for preventing leakage of process fluid from said inlet channel,

said flow collector including an outlet aligned with said passage of said second end cap, said flow collector outlet and said passage of said second end cap defining a process fluid outlet channel, said second end cap further including a seal located between said second end cap and said flow collector for preventing leakage of process fluid from said outlet channel,

whereby said compression module remains free of process fluid contamination during use.

24. The chromatography apparatus of claim 18 further comprising a pressure source connected to said compression module.

25. The chromatography apparatus of claim 18 wherein said compression module has a pressure rating greater than 3 bars.

26. The chromatography apparatus of claim 18 wherein said compression module has a pressure rating greater than about 5 bars.

27. The chromatography apparatus of claim 18 wherein said compression module has a pressure rating greater than about 10 bars.

28. The chromatography apparatus of claim 18 wherein said compression module has a pressure rating greater than about 15 bars.

29. A chromatography cartridge assembly comprising

a flexible walled cartridge defining a chamber for containing chromatography media,

a flow distributor for distributing process fluid across a cross-sectional area of said chamber,

a flow collector for collecting process fluid from across a cross-sectional area of said chamber, and

two sieves, one on either end of said chamber, for retaining the chromatography media in said chamber, said sieves preventing passage of the media therethrough while permitting passage of the process fluid therethrough,

said flow distributor, said flow collector, and said sieves being formed of hydrophilic material.

30. The chromatography cartridge assembly of claim 29 wherein said hydrophilic materials have a surface energy greater than about 36 dyn/cm.

31. A chromatography method comprising

providing a chromatography cartridge assembly comprising a cartridge including a flexible wall defining a chamber, and a porous, polymeric, hydrophilic,

chromatography media contained within said chamber, said flexible wall forming a movable diaphragm for radially compressing said chromatography media,

applying compression to said chromatography media, and

supplying a pressurized biomolecule sample in an aqueous based solvent.

32. The method of claim 31 wherein said sample is supplied at a pressure greater than 3 bars.

33. The method of claim 31 wherein the compression applied to said chromatography media is greater than or equal to the pressure of said sample.

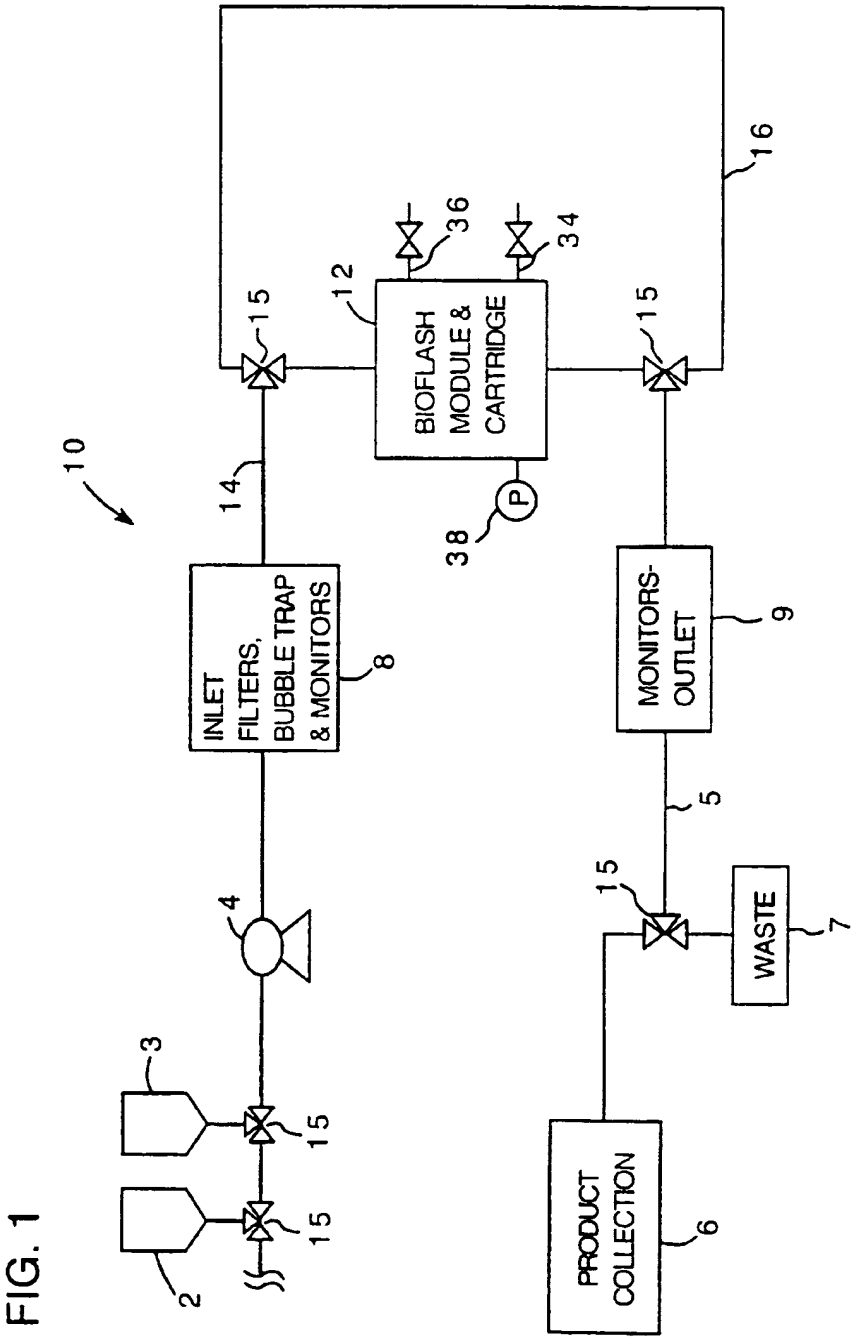
34. The method of claim 31 wherein said compression comprises radial compression.

35. The method of revitalizing a packed column having trapped air, comprising

providing a chromatography cartridge assembly comprising a cartridge including a flexible wall defining a chamber, and a porous, polymeric, hydrophilic, chromatography media contained within said chamber, said flexible wall forming a movable diaphragm for compressing said chromatography media, and

applying compression to said chromatography media to minimize the volume of trapped air.

36. The method of claim 35 wherein said compression comprises radial compression.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BIOFLASH MODULE & CARTRIDGE
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PRODUCT COLLECTION
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FIG. 1

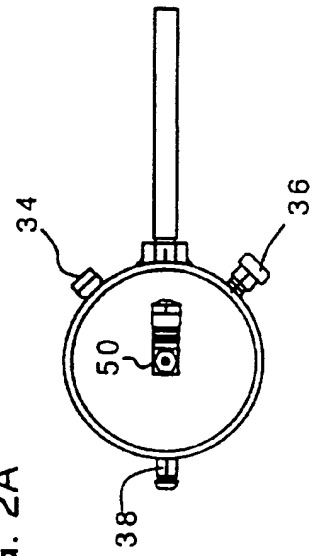


FIG. 2A

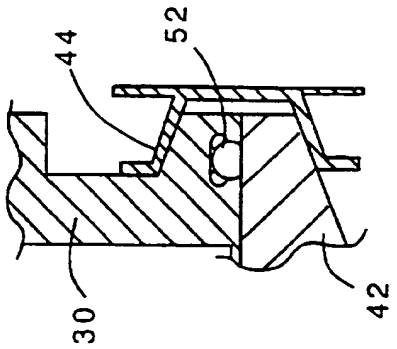


FIG. 2B

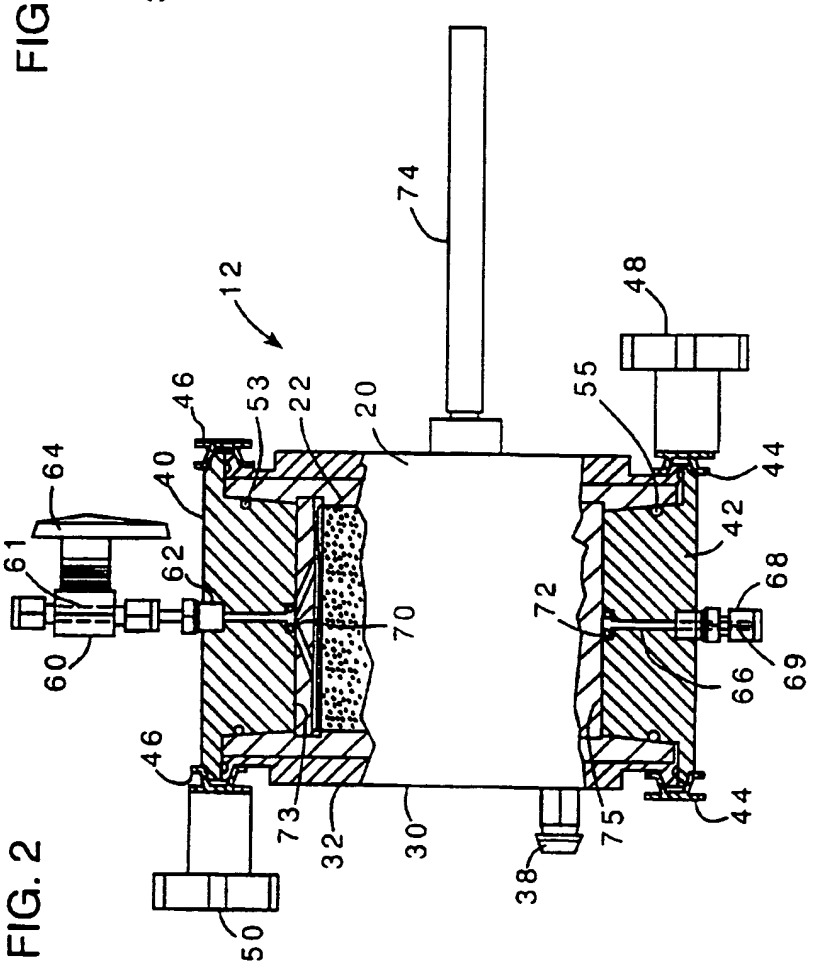
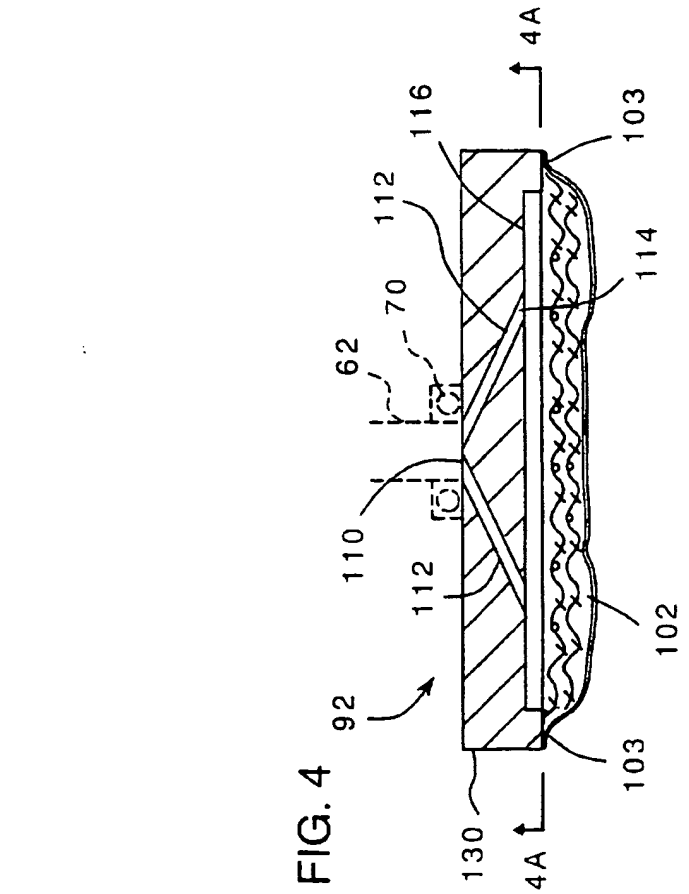


FIG. 2


4A
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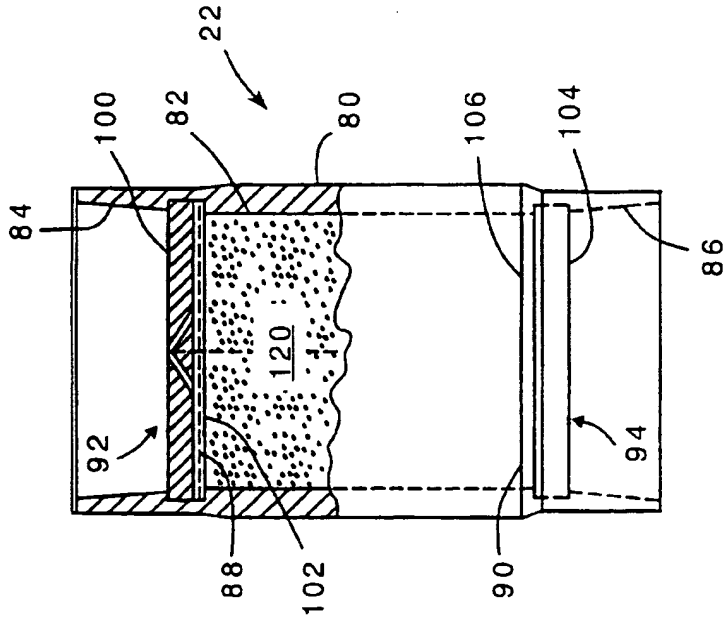
130
4A

FIG. 4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120
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94
88
102
90

FIG. 3

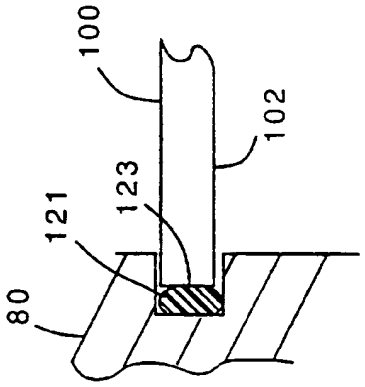

FIG. 5

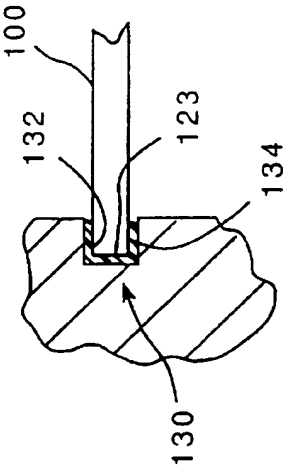

FIG. 6

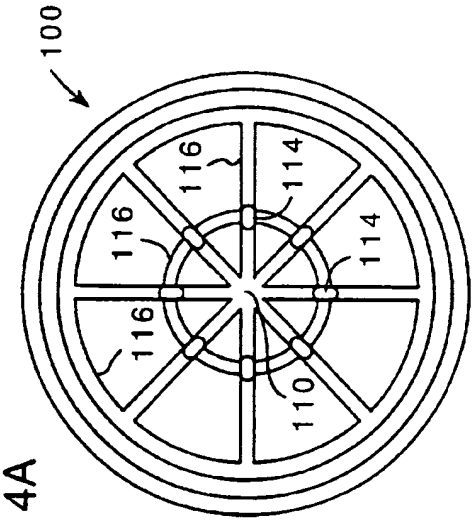

FIG. 4A

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US97/07210

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :B01D 15/08
US CL :210/635, 656, 188, 198.2, 456
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 210/635, 656, 659, 188, 198.2, 232, 282, 456; 95/82; 96/101, 106

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4,250,035 A (McDonald et al) 10 February 1981, col. 4, lines 20-25	1-36
Y	BioSepra, Chromatography Products Catalog and Price List, "HyperDiffusion Chromatography", April 1995, pages 6, 7, and 13, especially page 6, col. 1, lines 1-11	1-36

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E"	earlier document published on or after the international filing date	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&"	document member of the same patent family
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search	Date of mailing of the international search report
03 JUNE 1997	25 JUN 1997
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer ERNEST G. THERKORN Telephone No. (703) 308-0362

Form PCT/ISA/210 (second sheet)(July 1992)*